Introduction

Gomez and Sullivan conducted hydraulic modeling (HEC-RAS) of the Lamprey River in the Macallen Dam impoundment as part of a study for the Town of Newmarket (Town) to evaluate the feasibility of potentially removing the dam. As part the study, the depth of water above the existing Macallen Dam spillway will be calculated under a variety of flows, which will require quantifying the Macallen Dam spillway's weir coefficient. The weir coefficient is part of the weir equation, which is used to calculate a spillway's flow capacity. The weir equation is described by the equation:

$Q = CLH^{1.5}$, where

- Q = is quantity of flow passing over the weir (cfs),
- C= is the weir coefficient (feet$^{0.5}$),
- L= is the length of the weir (feet), in this case the length of the spillway is 70 ft, and
- H= is the depth of water above the weir crest (feet).

The purpose of this memo is to describe the process for estimating the Macallen Dam's weir coefficient.

The Lamprey River HEC-RAS model developed by Wright-Pierce (W-P) for the Town was obtained. W-P used their model to conduct work associated with their dam break and classification analysis. The objective of their work was to determine the Macallen Dam's 100-yr flood flow (while following NHDES guidelines) and the Macallen Dam's hazard classification. The final report, dated February 6, 2013, describes the work conducted by W-P, including the dam's 100-yr flood flow (10,259 cfs) and the dam's hazard classification (high). The report also includes a cost estimate for several potentially feasible alternatives to bring the dam into compliance with NHDES Dam Bureau dam safety requirements for a high hazard dam[1]. In reviewing the W-P HEC-RAS model and Appendix G of the February W-P report, it was noted that a weir coefficient of 2.60 and 2.63 was used in the model and report calculations, respectively.

Methodology

Gomez and Sullivan typically estimates weir coefficients by referencing the Handbook of Hydraulics, by Brater and King. The sixth edition is cited in this document for convenience,

[1] NHDES Dam Bureau dam safety rules require a dam to pass the design flow with 1-ft of freeboard and no manual operations. The design flow for the Macallen Dam, which is classified as High Hazard, was determined by the W-P study to be the 100-yr flood flow (10,259 cfs).

since the seventh edition has converted all of the equations, tables and coefficients to SI units from English units.

While 2.63 is commonly cited as the weir coefficient for a broad-crested weir, Brater and King notes that the weir coefficient can change with the water height, H (depth of water over the spillway):

"*Experiments on broad-crested weirs have been performed by Blackwell, Bazin, Woodburn, the U.S. Deep Waterways Board, and the U.S. Geological Survey. These experiments cover a wide range of conditions as to head, breadth, and height of weir. Considerable discrepancy exists in the results of the different experimenters, especially for heads below 0.5 ft. For heads from 0.5 to about 1.5 ft the coefficient becomes more uniform, and for heads from 1.5 to that at which the nappe becomes detached from the crest, the coefficient as given by the different experiments is nearly constant and equals approximately 2.63. When the head reaches one to two times the breadth, the nappe becomes detached and the weir becomes essentially sharp-crested. The effect on discharge of roughness of the crest can be computed by applying the principals of flow in open channels.*"

The dam's geometry is different from a typical broad-crested weir. In particular, the dam features a sloping upstream face (2:1 slope, 3.5-foot rise, 7-feet long), with a 1 foot high by 2.5-foot wide "step" on the top of the dam (Figure F-1). There is also a small metal lip in the center of the spillway that is approximately 2 inches high tall. Given the dam's shape, it is possible that the dam's spillway could act more like a trapezoidal weir under certain flow conditions. To remain conservative (i.e., not overestimate the spillway flow capacity), however, it is recommended that the dam be modeled as a broad-crested weir rather than as a trapezoidal weir.

Results

Brater and King

Table 5-3 in Brater and King (Figure F-2) tabulates weir coefficients for various weir head and breadth combinations for broad crested weirs. If the flow is high enough to produce 4 feet of head, with a breadth of 2.5 feet, then Table 5-3 would indicate a weir coefficient of 3.32. If we look in Brater and King Table 5-11 (Figure F-3), which is for trapezoidal weirs with a sloped upstream face and a downstream vertical face (similar to Macallen Dam), the weir coefficient for a 2:1 (horizontal:vertical) sloped upstream face such as Macallen Dam may be as high as 3.64-3.73, depending on the crest width. Again, while the dam may act more like a trapezoidal weir under some conditions, it is prudent to model the dam spillway as a broad crested weir. Thus, under conditions where the head is 4.0 feet or higher, it is recommended to model the

Macallen Dam spillway with a weir coefficient of 3.32. For model scenarios that produce less than 4.0 ft of head, or alternatives where the dam breadth is increased, it will be necessary to re-evaluate the spillway's weir coefficient using Brater and King's Table 5-3.

Empirical Data

The New Hampshire Fish and Game Department (NHFGD) provided GSE with measured water depths from a consistent location near the Dam's west retaining wall during the eel passage season from 2001 through 2007. The daily average flows at the Packers Falls USGS gage during the measurements ranged from 11 cfs to 1,910 cfs. The measured depths were not measured relative to the spillway crest, so the crest elevation was estimated by extrapolating the measurements at low flows (measurements were taken at flows as low as 11 cfs) to the approximate elevation at 0 cfs. The readings were then normalized to the estimated crest elevation. Water depth measurements indicated the water surface elevation was no more than 3 feet above the spillway crest under all measured conditions, so it was assumed that there was no flow diversion into the Oyster River basin.

The data were plotted versus drainage-area prorated daily average flows from the Packers Falls USGS Gage (Figure F-4). Two elevation versus flow rating curves were developed using the weir equation, with one curve assuming C=2.63 and one curve assuming C=3.32. The flow versus elevation curve assuming C=3.32 appeared to fit the data better than the curve assuming C=2.63.

Conclusion

This document described our proposed method for calculating the Macallen Dam spillway's weir coefficient. GSE plans on modeling the spillway as a broad-crested weir and use the weir coefficients listed in Table 5-3 of Brater and King's sixth edition. For heads greater than 4.0 feet, this translates to a weir coefficient of 3.32. Historic water surface elevation measurements collected by NHFGD were used to validate this estimation. The validation data showed that a weir coefficient of 3.32 was appropriate for heads between 0.5 and 2.0 feet. One can expect the weir coefficient at higher heads to remain at or above those measured at lower heads. Thus, a weir coefficient of 3.32 appears to be appropriate for most situations we will model in this study.

A weir coefficient of 3.32 is approximately 26% higher than the 2.63 weir coefficient used in the W-P report. This translates into the spillway being able to pass 26% more flow than W-P estimated, for a given headwater elevation. Therefore, our hydraulic model and calculations will show lower water surface elevations than the W-P report indicated, when comparing similar flows. This may also reduce the portion of flow that diverts to the Oyster River at the Route 108 flow split under high flow events.

Figure F-1: Side-view of Macallen Dam.

Table 5-3. Values of C in the Formula $Q = CLH^{3/2}$ for Broad-crested Weirs

Measured head in feet, H_e	Breadth of crest of weir in feet									10.5 *	
	0.50	0.75	1.00	1.50	2.00	2.50	3.00	4.00	5.00	10.00	15.00
0.2	2.80	2.75	2.69	2.62	2.54	2.48	2.44	2.38	2.34	2.49	2.68
0.4	2.92	2.80	2.72	2.64	2.61	2.60	2.58	2.54	2.50	2.56	2.70
0.6	3.08	2.89	2.75	2.64	2.61	2.60	2.68	2.69	2.70	2.70	2.70
0.8	3.30	3.04	2.85	2.68	2.60	2.60	2.67	2.68	2.68	2.69	2.64
1.0	3.32	3.14	2.98	2.75	2.66	2.64	2.65	2.67	2.68	2.68	2.63
1.2	3.32	3.20	3.08	2.86	2.70	2.65	2.64	2.67	2.66	2.69	2.64
1.4	3.32	3.26	3.20	2.92	2.77	2.68	2.64	2.65	2.65	2.67	2.64
1.6	3.32	3.29	3.28	3.07	2.89	2.75	2.68	2.66	2.65	2.64	2.63
1.8	3.32	3.32	3.31	3.07	2.88	2.74	2.68	2.66	2.65	2.64	2.63
2.0	3.32	3.31	3.30	3.03	2.85	2.76	2.72	2.68	2.65	2.64	2.63
2.5	3.32	3.32	3.31	3.28	3.07	2.89	2.81	2.72	2.67	2.64	2.63
3.0	3.32	3.32	3.32	3.32	3.20	3.05	2.92	2.73	2.66	2.64	2.63
3.5	3.32	3.32	3.32	3.32	3.32	3.19	2.97	2.76	2.68	2.64	2.63
4.0	3.32	3.32	3.32	3.32	3.32	3.32	3.07	2.79	2.70	2.64	2.63
4.5	3.32	3.32	3.32	3.32	3.32	3.32	3.32	2.88	2.74	2.64	2.63
5.0	3.32	3.32	3.32	3.32	3.32	3.32	3.32	3.07	2.79	2.64	2.63
5.5	3.32	3.32	3.32	3.32	3.32	3.32	3.32	3.32	2.88	2.64	2.63

Figure F-2: Weir-coefficients from Brater and King (sixth edition) for broad crested weirs, as a function of dam breadth and water height above the weir crest.

Table 5-11. Values of C in the Formula $Q = CLH^{3/2}$ for Weirs of Trapezoidal Cross Section with the Upstream Face Inclined and the Downstream Face Vertical

Slope of upstream face	Width of crest in feet	Head in feet, H								
		1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
Hor. Vert.										
2 to 1	0.33	3.85	3.82	3.79	3.77	3.75	3.73	3.70	3.67	3.64
2 to 1	0.66	3.41	3.57	3.65	3.70	3.72	3.72	3.73	3.73	3.73
3 to 1	0.66	....	....	3.57	3.57	3.57	3.57	3.57	3.57	3.57
4 to 1	0.66	....	....	3.48	3.48	3.48	3.48	3.48	3.48	3.48
5 to 1	0.66	....	....	3.39	3.39	3.39	3.39	3.39	3.39	3.39

Figure F-3: Weir coefficients from Brater and King (sixth edition) for trapezoidal weirs with a sloped upstream face and a vertical downstream face.

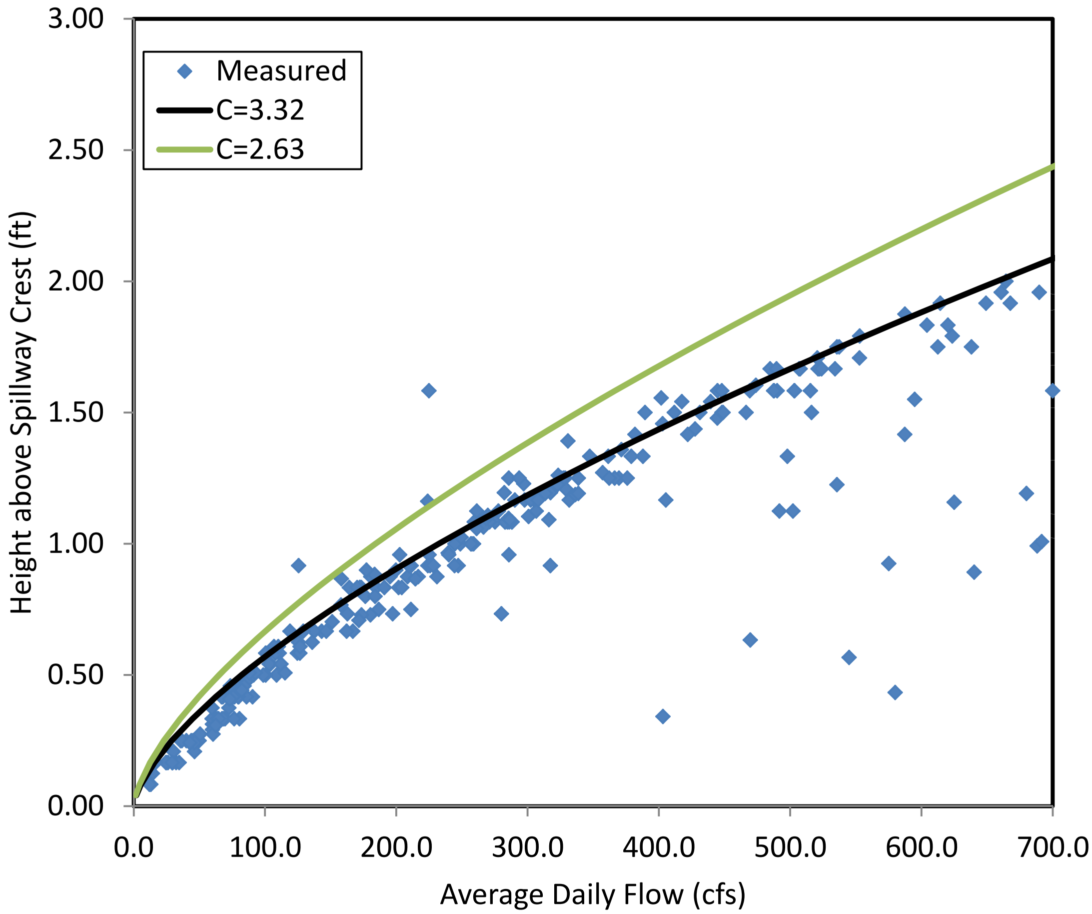

Figure F-4: Flow vs. water depth measurements and calculations for two different weir coefficients (2.63 and 3.32). Additional measurements at daily average flows greater than 700 cfs are not shown. Measurements at higher flows (> 250 cfs) with lower heights above the spillway crest than the curve show may be due to the dam gates being opened during the measurements.